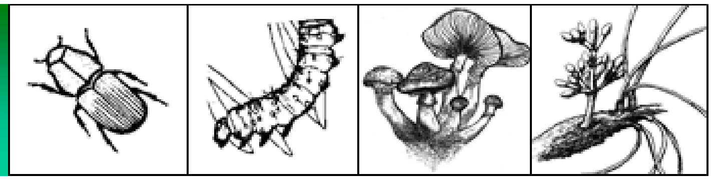
Forest Health Protection



16-08 **June, 2016**

Hazard Rating Bark Beetle Activity in Pine Species Using the Northern Region Vegetation Map (R1-VMap)

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EXECUTIVE SUMMARY

Land managers often use plot data to assign pine bark beetle hazard ratings for lodgepole pine (LPP), ponderosa pine (PP), western white pine (WWP), whitebark and limber pines (WBkP-LmP), and all pine species (ALLPINE) (Randall et al., 2011). The USDA Forest Service Northern Region (R1), developed pine bark beetle hazard ratings (very low, low, moderate, or high) for lodgepole pine (LPP), ponderosa pine (PP), western white pine (WWP), whitebark and limber pines (WBkP-LmP), and all pine species (ALLPINE) (Randall et al., 2011). These hazard ratings are available for all inventory data, both stand exam and Forest Inventory and Analysis (FIA) plot data residing in the National Forest Systems Vegetation Database, FSVeg and for growth and yield simulations using the Forest Vegetation Simulator (FVS).

Since stand exam data can be attributed with pine beetle hazard, this information can be displayed with the associated stand polygon layer. However, because many stands have not been examined, or stand exam data is outdated, hazard maps may not be contiguous or current. It was desired to produce a spatial layer of pine beetle hazard rating, for the Region that could be used by land managers.

The Northern Region has an existing vegetation classification system (Barber et al., 2011) which determines dominant tree species, tree size class, and canopy cover class. This classification system meets national tech guide standards as defined in the USDA Forest Service Existing Vegetation Classification, Mapping, and Inventory technical guide (Citation, the one below is old). This classification system be applied to inventory data and is used to derive the existing vegetation spatial database for the Northern Region. The Northern Region Vegetation Mapping Project (R1-VMap) (Brewer et al., 2004) is the most current, region-wide spatial database depicting existing vegetation. This spatial dataset displays the following vegetation attributes: species dominance type, tree size class, and tree canopy cover class. R1-VMap meets, and in many cases exceeds, the requirements of an existing vegetation system as defined in the USDA Forest Service Existing Vegetation and Mapping Technical Guide (Nelson et al., 2015) and the National Vegetation Classification Standard (FGDC NVC, 2008). R1-VMap includes lands of other ownerships near and within National Forest boundaries, and can be used to create specialized map products useful to land managers

A spatially balanced sample of inventory plots (n=3324) were used to explore the relationship of pine beetle hazard to R1-ExVeg classifications for dominance group, size class, and canopy cover class with the goal of assigning pine beetle hazard to R1-VMap. Based on our analysis we determined that R1-ExVeg attributes of dominance group 60% plurality (Dom60) and tree size best predicted pine bark beetle hazard rating class. Using a standard rule base we assigned the beetle hazard rating that best fit each Dom60 / tree size class in the R1-VMap which provides a region-wide pine beetle hazard spatial

depiction. In addition, we explore options for customizing this process for individual National Forests. Other methods could have been used to assign hazard to plots and/or R1-VMap.

The resulting beetle hazard maps are subject to the same strengths and weaknesses inherent in the base R1-VMap data. Thus, care should be taken in using them at appropriate spatial scales. In addition, hazard ratings, in themselves, do not provide a direct measure of tree mortality, although it may be possible in the future to predict tree loss in R1-VMap polygons, based on their hazard rating, particularly for mountain pine beetle at epidemic levels.

INTRODUCTION

Pine bark beetles, predominantly mountain pine beetle (MPB) (*Dendroctonus ponderosae* Hopkins) and to some degree western pine beetle (WPB) (*Dendroctonus brevicomis* LeConte), are the most destructive bark beetles (Coleoptera: Scolytidae) in western North America and may conflict with pine species management objectives. For significant pine bark beetle-caused mortality to occur, three things are necessary: 1) suitable host trees, 2) pine bark beetle populations, and 3) favorable weather conditions. Of these three the only factor land managers can influence is the amount and arrangement of suitable host trees. A landscape-level map identifying forested areas most susceptible to significant pine bark beetle impacts can help Northern Region (R1) National Forest managers determine where limited management resources can be dedicated.

Pine bark beetle hazard rating systems which use stand characteristics such as basal area (BA), average tree diameter at breast height (DBH), and percent of susceptible host species in the stand, enable land managers to identify forested areas at high risk to significant pine-volume loss where current stand information is available (see Randall et al. 2011). As stand exams are conducted less frequently, the area covered by and the accuracy of stand-based hazard rating maps has diminished.

The Northern Region Vegetation Mapping Project (R1-VMap) (Brewer et al., 2004) is the most current, region-wide existing vegetation spatial layer. This spatial dataset contains vegetation attributes as defined by the Northern Region's Existing Vegetation Classification System (R1-ExVeg) (Barber, Bush, & Berglund, 2011). R1-VMap meets, and in many cases exceeds, the requirements of an existing vegetation system as defined in the USDA Forest Service Existing Vegetation and Mapping Technical Guide (Nelson et al., 2015) and the National Vegetation Classification Standard (FGDC NVC, 2008). R1-VMap includes lands of other ownerships near and within National Forest boundaries, and can be used to create specialized map products useful to land managers. Our goal was to take R1-VMap and create a protocol that allows managers to assign pine bark beetle hazard, useful in management decisions.

METHODS and RESULTS

DATA RESOURCES

R1 Existing Vegetation Classification System (R1-ExVeg) and Vegetation Map (R1-VMap)

The Northern Region Existing Vegetation Mapping Program (VMap) database and map products provides the Northern Region with a geospatial database of existing vegetation produced using consistent analytical methodology according to the Existing Vegetation Classification and Mapping Technical Guide (Nelson, et. Al. 2015) to support the Region 1 Multi-level Classification, Mapping, Inventory, and Analysis System, R1-CMIA (Berglund et. al., 2009). The VMap database provides four primary map products; lifeform, tree canopy cover class, tree size class, and tree dominance type to support mid- and base-level analysis and planning. VMap uses the Region 1 Existing Vegetation Classification System (R1-ExVeg) (Barber, et.al. 2009) in its map unit design. The system was designed to allow consistent applications between Regional inventory and map products within the R1-CMIA framework. VMap is a remote sensing derived product. As such, it uses a combination of high resolution airborne imagery and a nationally available digital elevation model (DEM). An accuracy assessment is conducted to provide a

validation of the data, giving an indication of reliability of the map products, so that managers are fully informed throughout the decision making process. Estimates of overall map accuracy and confidence of individual map classes can be inferred from the accuracy assessment error matrix derived from the comparison of known reference sites to mapped data.

R1 Summary FIA Plot Inventory Database (R1-SDB)

Forest Inventory and Analyses (FIA) plot data (USDA Forest Service 2016) provides a spatially balanced, statistical sample appropriate to use for broad level planning and analysis (Bush, 2014). It covers all lands regardless of land-use designation or management history, making it representative of vegetation across the Region. The FIA inventory used for this hazard rating was reasonably current with plots installed by FIA between the 1993 and 2002 period (periodic inventory plots). In 2003, Interior West (IW) FIA started an annual inventory which re-measures 10% of the plots every year. These newer plots were not available during model development. The periodic data in the Northern Region's FS-VEG R1-SDB database (R1-SDB ver. 2003) covered 3423 forested FIA plots located on Forest Service lands. However, 99 plots had no vegetation type (all were "non-forest") and were dropped so that 3324 plots were used in our analyses.

Pine Bark Beetle Hazard Ratings Using Plot Data (Plot Hazard)

Pine bark beetle hazard ratings for five different pine hosts were assigned to the FIA plots. The criteria for assigning each of the pine bark beetle hazard rating classes (Table 1) to inventory data is summarized in Randall and others (2011). Each plot's pine bark beetle hazard ratings were accurate as of the time of plot inventory. All plots were surveyed prior to the current MPB outbreak, and hazard ratings only needed to apply to the plot for the date data was collected, no attempts were made to "grow" plots from the date of the last inventory to the present.

Abbreviations for the five pine host models are:

- ALL PINE: Pine bark beetles in all pine species
- LPP: Mountain pine beetle in lodgepole pine
- PP: Bark beetles in ponderosa pine (includes mountain pine beetle, possible *Ips* species, and western pine beetles west of the Continental Divide).
- WWP: Mountain pine beetle in western white pine
- WBkP-LmP: Mountain pine beetle in whitebark and limber pines

Table 1: Description of Hazard Rating Classes

CODE	DESCRIPTION
0	VERY LOW HAZARD: host trees are not present in the plot data; pine bark beetle impact is expected to be minimal or non-existent
1	LOW HAZARD: host trees are either not abundant and/ or of sufficient size to be susceptible to pine bark beetle attack resulting in pine mortality
2	MODERATE HAZARD: plot data indicates that there are enough host trees of the appropriate size to be susceptible to pine bark beetle attack and subsequent pine mortality
3	HIGH HAZARD: plot data indicates that there are enough host trees of the appropriate size to be susceptible to pine bark beetle attack and significant subsequent pine mortality
4	NO HAZARD: non-forested lands

The total number of FIA plots in each of the four hazard classes for each of the five pine host models is given in Table 2.

Table 2. Number of plots in each hazard class by pine host hazard rating

Hazard Rating	ALL PINE	Lodgepole	Ponderosa	Whitebark/ Limber	Western white*
0	885	1745	2907	2484	1861
1	521	393	117	444	232
2	1094	750	256	270	99
3	824	436	44	126	0
TOTAL	3324	3324	3324	3324	2192*

*Western white pine is modelled for west of Continental Divide only

Vegetation Attributes (R1-ExVeg)

Each FIA plot was classified into dominance type, tree size, and tree canopy cover classes using the R1-ExVeg classification system (Barber, Bush, & Berglund, 2011). These classifications are described below.

Dominance Type

R1-ExVeg dominance type describes tree species composition in a forest.

- Dominance group 6040 (DG6040) is based on whether the dominant tree species constitutes ≥60%, 59-40%, or <40% of the stand (based on logic using one or more factors of canopy cover, BA, or trees per acre but for stands with >=20 ft^2 total BA dominance is usually based on relative BA). While DG6040 is the finest thematic dominance group classification system mapped in R1-VMap, mapping personnel did not feel there was an adequate accuracy assessment for this classification system for mid- and broad-level assessments. For this reason we did not consider DG6040 as the vegetation dominance group classification for the R1-VMap hazard rating system.
- Dominance 60% plurality (Dom60) classes include only single-species classes and mixed-species classes. This creates a map or inventory compilation with classes that are based on ≥ 60% abundance of an individual species and three heterogeneous mixed species classes. Dom60 classes are most useful when the management question of interest requires relatively pure vegetation types.
- Dominance 40% plurality (Dom40) classes consolidate all single species classes and single species-mixed species classes together based on the dominant species present. This creates a map or inventory compilation with classes that are based on ≥40% abundance.

Size Class

Tree size is a classification of the predominant DBH of live trees within a plot. Size class for inventory data is based on basal area weighted average diameter. Each plot is assigned one of four tree size classes:

- Seedling- ≤4.9” DBH
- 5.0”-9.9” DBH
- 10.0”-14.9” DBH
- ≥15”+ DBH

Canopy Cover

Tree canopy cover describes the proportion of the forest floor covered by the vertical projection of the tree crown. . For inventory data, canopy cover is calculated using the Forest Vegetation Simulator (FVS)Each plot is assigned one of five tree canopy cover classes:

- 0-9.9%
- 10-24.9%
- 25-39.9%
- 40-59.9%
- 60% +

Continental Divide

Past and current climate, vegetation, and insect activity can differ based on whether you are on the east or west side of the Continental Divide (CD). In general, Forests in the Northern Region reside on one side or another of the CD. For a few Forests some boundaries do cross over this line, however, this is often minimal. Thus, plots were assigned as east or west based on which Forest they occurred on (Table 3).

Table 3. National Forests (and identification number) in the Northern Region identified as principally east or west of the Continental Divide

EAST SIDE	WEST SIDE
Beaverhead-Deerlodge (2)	Bitterroot (3)
	ID Panhandle (4)
Custer (8)	Clearwater (5)
Gallatin (11)	Flathead (10)
Helena (12)	Kootenai (14)
Lewis & Clark (15)	Lolo (16)
	Nez Perce (17)

PROCESS

In existing hazard rating systems, hazard rating classes are assigned to stands based on plot level data. R1-VMap polygons do not have plot level data, but they do have R1-ExVeg classes that can be used as surrogate stand descriptions. In order to create pine bark beetle hazard rating maps using R1-VMap, pine beetle hazard ratings had to be assigned to one or a combination of R1-ExVeg class attributes available in R1-VMap.

Determining R1-ExVeg Attributes Best for Modelling

The first step in creating pine bark beetle hazard rating maps using R1-VMap required analyses of FIA plot inventory data (R1-SDB) to determine which R1-ExVeg vegetation attributes best predict beetle hazard rating.

Through graphing and summarizing exercises we found moderate and high pine bark beetle hazard ratings were concentrated in fewer Dom60 classes than Dom40 classes, although there were an equal number of classes in DG60 and DG40 represented in the FIA plot data. Overall results indicated that the DG60 classification system did a better job of identifying stands with significant host components than DG40.

We then used the R statistics program (R Development Core Team, 2011), *rpart* module (Therneau and Atkinson, 2011) to evaluate R1-ExVeg variables of Dom60, size class, canopy cover, and CD for their importance in predicting pine bark beetle hazard rating classes. Results of *rpart* showed Dom60 to be the primary variable of importance in predicting a plots pine bark beetle hazard class for all four individual host models, followed in importance by tree size class. If tree canopy cover was determined to contribute to explaining hazard, it was usually the 3rd factor in the host model (Table 4).

Continental Divide was identified as the primary variable for the WBkP-LmP model (Table 4). However, it is likely the importance of Continental Divide is an artifact of MPB-caused mortality in this host type

west of the Divide several decades prior to collection of FIA periodic data. We do provide both an East and a West version of the WBkP-LmP hazard model (Appendix C) that Forests may explore to determine if these better depict what is expected in their area. The Regional model, however, is recommended for use if close comparison of models is not done.

Table 4. Order of importance of variables used to build the best model for predicting pine beetle hazard for 4 habitat grouping. Variables given for the first 3 splits, all branches. An 'X' indicates the branch dead ended; '*n/a*' indicates no applicable data available (branch terminated previously).

HAZ RATING	1st SPLIT	2nd SPLIT	3rd SPLIT
ALL PINES	Dominance Type	Size Class Size Class	X Size Class. X Dominance Type
LODGEPOLE	Dominance Type	X Dominance Type	*(n/a)* *(n/a)* Size Class Size Class
PONDEROSA	Dominance Type	X Size Class	*(n/a)* *(n/a)* X Canopy Cover
WHITEBARK / LIMBER	Continental Divide	X Dominance Type	*(n/a)* *(n/a)* X Dominance Type

Assessing Model Error Rates

Overall Model Error

Regional rating of plot-level data for pine bark beetle hazard is based on considerable published literature (See Randall et al., 2011) and makes use of a range of detailed inventory data. However, data currently available in R1-VMap is much less detailed, with categorized variables that may not reflect divisions that are biologically relevant to pine bark beetles. Generalization of the rating system to a few categorical factors, when hazard is based on more detailed stand information should be recognized as a significant source of error. Thus, it is be important to understand how well these R1-VMap values serve as substitutes in describing plot-level hazard.

In addition to using the R statistical package, *RandomForest* (Liaw and Wiener, 2002) was used to further test whether the two-factor model we had chosen using *rpart* was the most appropriate model using overall model error rates. Comparison of possible models using R module *RandomForest* supports the importance of Dom60, followed in importance by Size Class and Canopy Cover (Table 5). Across all five host models and for ALL PINES in particular, the best performing variable model with least number of factors was usually Dom60/Size Class. In a few cases other models performed equally well.

Table 5: Error rates (rounded to closest 1%) for all possible variable models for each pine host hazard rating. Values in blue print indicate models with lowest errors or equal-to-lowest error with fewest variables (simplest model).

VARIABLE MODEL	ALL PINE	Lodgepole	Ponderosa	Whitebark / Limber	Western White
Dom60	49%	38%	11%	23%	15%
Dom60 + Canopy	46%	35%	10%	23%	15%
Canopy + Size	55%	45%	13%	25%	15%
Dom60 + Size	43%	33%	10%	23%	15%
Dom60 + Size + Canopy	43%	34%	10%	23%	15%
Dom60+Size+ Continental Divide	43%	34%	11%	24%	n/a

Table 6: Individual hazard rating error rates for all pine species (ALL PINE) for each of the six variable models tested. See text for more detail on how to interpret numbers.

ALL PINES

PREDICTED HAZARD (columns) / **ACTUAL PLOT HAZARD RATING** (rows)

DomGroup 60% Plurality

	0	1	2	3	error
0	606	5	274	0	32%
1	217	21	179	104	96%
2	373	8	528	185	52%
3	33	7	252	532	35%

DomGroup 60% Plurality*Size Class

	0	1	2	3	error
0	635	36	183	31	28%
1	158	177	163	23	66%
2	363	30	498	203	54%
3	35	3	203	583	29%

DomGroup 60% Plurality*Canopy Cover

	0	1	2	3	error
0	539	28	302	16	39%
1	192	107	163	59	79%
2	299	22	598	175	45%
3	43	0	216	565	31%

Size Class*Canopy Cover

	0	1	2	3	error
0	415	40	324	106	53%
1	68	188	172	93	64%
2	226	34	604	230	45%
3	116	3	404	301	63%

DomGroup 60% Plurality*Size Class *Canopy Cover

	0	1	2	3	error
0	559	53	245	28	37%
1	175	155	171	20	70%
2	312	22	587	173	46%
3	34	0	210	580	30%

DomGroup 60% Plurality*Size Class *CanopyCover*Continental Divide

	0	1	2	3	error
0	589	51	227	18	33%
1	179	160	156	26	69%
2	324	29	536	205	51%
3	34	1	178	611	26%

Error by Hazard Class:

RandomForest was also used to provide prediction error rates for individual hazard rating classes, i.e. how well did our models using R1-ExVeg categories predict the plot hazard ratings. So, whereas the ALL PINE hosts model using Dom60/Size Class as factors had an overall error of 43% (Table 5), individual hazard rating level errors are 28%, 66%, 54%, and 29% for hazards of VERY LOW (0), LOW (1), MODERATE (2), and HIGH (3), respectively (Table 6).

To understand the confusion matrix reported by *RandomForest* output (Table 6), consider that each row represents all FIA plots within the hazard rating class given on the left (based on plot variables). Along the row, individual columns show how many of those plots the new model (using vegetation classifications for Dom60 and Size Class) predicted would be in each hazard rating. For example, in the model shown in Table 6 using only Dom60 to predict hazard, of the 824 FIA plots with a HIGH (3) hazard rating (33+7+252+532; also see Table 2), the 1-variable model correctly predicted 532 plots as being High hazard, placing most of the miss-categorized plots (33+7+252) into MODERATE (2) hazard (252).

Review of the individual hazard level ratings suggests that our preferred two-factor model of Dom60/Size Class does better at predicting areas with VERY LOW and HIGH hazards, which are usually the most important categories for land managers (Appendix A). LOW and MODERATE categories have higher error rates and should be used with caution.

Assigning Pine Bark Beetle Hazard Ratings to R1-VMap Polygons

Using the two-variable model that best predicted plot hazard for all five beetle host types, we then had to determine which hazard rating to assign each Dom60/Size Class vegetation group. Our process for assigning pine bark beetle hazard ratings (Table 1) to each combination of Dom60/Size Class used the logic outlined in Table 7. This logic is based on professional judgment, and efforts to reflect hazard ratings of ground plots that might have had similar dominance type and tree size class.

Table 7: Logic for assigning pine bark beetle hazard ratings to Dom60/Size Class vegetation groups. If the first statement is not true, proceed to second until you hit a "TRUE" statement.
1) If the percent of inventory plots with Very Low hazard (0) is >75%, then Dom60/Size Class hazard is Very Low (0);
Else go to 2
2) If the percent of inventory plots with High hazard (3) is >50% and >80% are in High (3) OR Moderate (2), then Dom60/Size Class hazard is High (3);
Else- go to 3
3) If the percent of inventory plots with High(3) OR Moderate (2) hazard is >40%, then Dom60/Size Class hazard is Moderate (2);
Else Dom60/Size Class hazard is Low (1)
(Non-forested areas are given a hazard category of 4)

While we had a large number of FIA plots for some Dom60/Size Class combinations, some combinations had few or no plots and we were forced to use expert opinion to assign a hazard rating. We wanted to capture the sample strength for the pine bark beetle hazard ratings assigned to each Dom60/Size Class combination. Thus, we also provide a sample strength indicator based on the number of inventory plots within each vegetation grouping as outlined in Table 8. These codes are used throughout Appendices B and C and are indicated by the color of the data cell.

Table 8: Description of Sample Strength Indicators (and color codes used in appendices)	
1	GOOD SAMPLE SIZE: FIA sample was sufficient to assess the hazard for vegetation group (n≥10 FIA plots in vegetation group). **(no color)**
2	SMALL SAMPLE SIZE: FIA sample was not sufficient to assess the hazard for vegetation group (n <10 FIA plots in vegetation group); Expert call supported by sample. **(gold)**
3	SMALL SAMPLE SIZE: FIA sample was not sufficient to assess the hazard vegetation group (n<10 FIA plots in vegetation group); Expert call different from sample. **(gold)**
4	NO SAMPLE: No FIA sample plots in DG60/ Size Class combination; Expert call on hazard. **(orange)**
5	NON-FORESTED: vegetation group was non-forested, so no hazard assigned. **(N/A)**

Attaching the hazard rating and sample strength codes to the R1-VMap polygons allows spatial depiction and analyses. Figure 1 shows what the ALL PINES hazard ratings are for Region 1, with a close up that also shows how sample strength has been presented in the current map available from Region 1 Engineering, Geospatial staff.

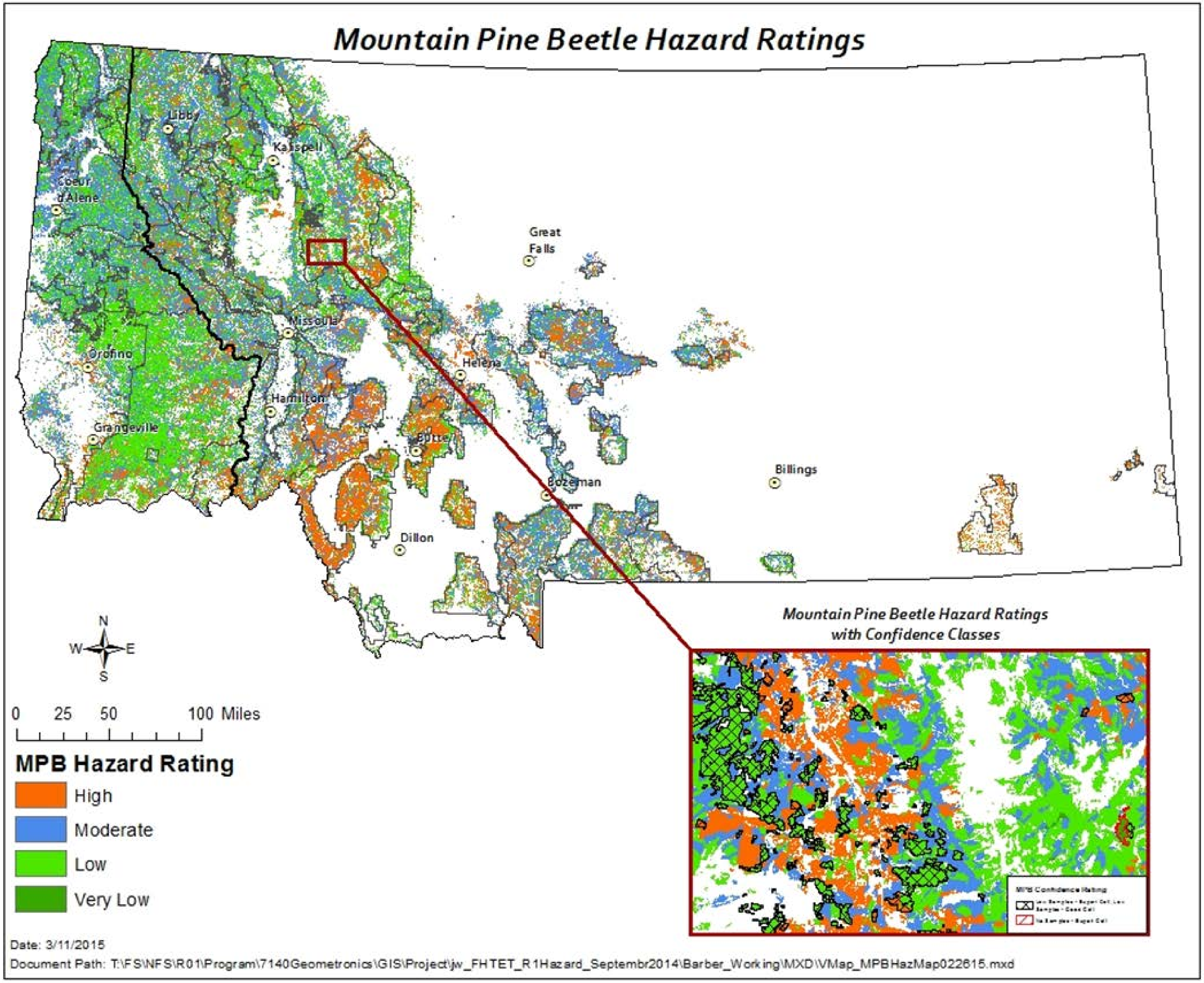


Figure 1. Map of mountain pine beetle hazard rating of ALL PINE model for R1-VMap. Sample strength indicator or "confidence class" is shown for a small area of the Region (insert).

DISCUSSION

EXPLORING ERROR OF HAZARD ASSIGNMENTS

The database of FIA plots with plot level hazard ratings was updated to include the new hazard rating corresponding to the Dom60/Size Class of that plot. With this, we further explored sources of error and error rates with the goal of possible refinement of the hazard rating model.

Comparing R1-VMap and R1-SDB for Forest-level hazard

We conducted an additional evaluation of the 3324 FIA plots to compare the estimates of hazard using Randall and others (2011) to the estimates of hazard using the equivalent R1-Veg classifications. Table 9 shows how well the two methods of hazard rating correspond. Note VERY LOW (0) and LOW (1) hazards were combined to smooth out the high variability between datasets for these two categories.

*Data suggests VERY LOW (0) and LOW (1) hazard ratings should be combined to provide most similar area estimates

Table 9: Comparison of area predicted to be in each of three hazard rating classes based on hazard ratings assigned using either Randall and others (2011) or R1-Veg Dom60/Size Class. The ALL PINE model results were used for all 3324 plots..

		BASED ON RANDALL ET AL HAZARD RATINGS			BASED ON DOM60/SIZE CLASS HAZARD RATING			DIFFERENCES BETWEEN THE TWO RATINGS**		
Forest Name (Number)	#of Plots	0&1* (very low + low)	2 (moderate)	3 (high)	0&1* (very low + low)	2 (moderate)	3 (high)	0&1* (very low + low)	2 (moderate)	3 (high)
B-D (2)	438	26%	29%	45%	25%	32%	43%	1%	-3%	2%
Custer (3)	91	26%	30%	44%	26%	20%	54%	0%	10%	-10%
Gallatin (11)	212	36%	28%	36%	30%	43%	26%	6%	-15%	9%
Helena (12)	134	34%	30%	36%	34%	32%	34%	0%	-2%	2%
Lewis & Clark (15)	259	40%	36%	24%	34%	38%	29%	6%	-2%	-4%
Bitterroot (3)	220	32%	37%	31%	40%	40%	20%	-7%	-4%	11%
Panhandle (4)	389	52%	36%	12%	45%	49%	6%	7%	-13%	6%
Clearwater (5)	285	60%	26%	14%	53%	36%	11%	7%	-11%	4%
Flathead (10)	335	50%	33%	17%	45%	40%	15%	5%	-7%	2%
Kootenai (14)	344	51%	35%	14%	40%	48%	13%	11%	-13%	2%
Lolo (16)	322	40%	38%	22%	30%	49%	20%	10%	-11%	2%
Nez Perce (17)	295	43%	34%	23%	49%	35%	16%	-6%	-1%	6%
REGION	3324	42%	33%	25%	38%	40%	21%	4%	-7%	3%

**In most cases, estimates differed by 10% or less, except where noted in red

Across the 12 Forests and Regionally the number of plots in VERY LOW+LOW, MODERATE, and HIGH hazard for both hazard rating methods are within 10% agreement. Five Forests have greater than 10% disparity in the MODERATE rating, with one Forest (Kootenai) also off >10% in the lowest hazard rating. In no case was disparity greater than 15%. Overall, this is a good level of agreement at the landscape level.

Note that this comparison was done on the older inventory plots. The depiction of error between the two hazard rating systems (Randall et al 2011 versus Dom60/Size Class) is appropriate, but the numbers are not indicative of current Forest-wide conditions. To obtain more current Forest-wide conditions, more recent inventory data (preferably after bark beetle, fire or other large disturbances were completed) would have to be used. Use of our rating system on newer R1-VMap coverages is discussed in the section on Exploring Error: Age of Data.

Note that VERY LOW and LOW hazard ratings were combined to obtain similar prediction levels. Stand level plot hazard ratings placed approximately 2/3 of VERY LOW and LOW hazard plot into VERY LOW with the other 1/3 into LOW (Regional estimate; Forest estimates averaged 3/5 and 2/5, respectively). Distribution of these lower hazard ratings based on R1-Veg classification put most plots into the LOW hazard with approximately 1/20 and 19/20 assigned to VERY LOW and LOW (respectively) both for the Region and as the Forest average. This may suggest that in our decision matrix (Table 6) our requirement that, for any Dom60/Size Class vegetation group, >75% of plots have a rating of VERY LOW (0) for the vegetation group to be classified as having VERY LOW (0) hazard is overly stringent; perhaps >51% would be more appropriate.

Classification error at plot level (mismatch error)

If we consider the hazard rating assigned to the R1-SDB FIA plots using Randal and others (2011) as being the best estimate of "real" MPB hazard and the hazard assigned to the R1-ExVeg classification (used in R1-VMap) as "estimated" or modelled hazard, a comparison of the two ratings will highlight Dom60 groups where errors are highest. Table 10 provides a summary view of mismatch in these hazard ratings. Of greatest concern are 1) errors in common Dom60 vegetation types and 2) errors greater than one rating of mismatch. Also, depending on the intended use of the map, modelled ratings that are lower than what might be expected on the ground may be of greater concern than if the model over estimates hazard in some polygons or plots.

Where the Forest-wide evaluation in Table 9 allowed higher and lower ratings to cancel each other out over the landscape, this evaluation of error is less forgiving. In general, we found that our modelled hazard ratings provide a correct match to the plot hazard rating 46% or about half of the time. Approximately 36% or one third of the time the model predicted a higher hazard than the FIA plots were given, and 18% of the time the model gave a lower hazard than the FIA plots. Taking the conservative approach and accepting where the model slightly overestimates hazard (i.e. mismatches of -1) we looked at the two situations that could cause the greatest concern to managers.

1. Mismatches where the model overestimated hazard by more than one level (i.e. mismatch of -2) that occurred more than 10% of the time (e.g. PIEN, PIFL2, PSME, TMIX in red highlight), and
2. Mismatches where the model underestimated hazard by any amount more than 25% of the time (e.g. ABGR, ABLA, IMIX in yellow highlight).

If we further explore only Dom60 types that make up a significant portion (>10%) of the landscape (in this case, the Region), we are left with IMIX, PSME, and TMIX as the vegetation types with the most errors of concern over the largest area. These three vegetation types make up approximately 56% of the FIA plots for the Region. Dom60 types with fewer than 10 plots do not have sufficient information for further dissection and make up too little of the landscape to evaluate at this level (grey highlight).

Where the Forest-level evaluation in Table 9 shows which Forests may benefit from a reevaluation of the models, this evaluation of mismatching hazard ratings by Dom60 suggests which vegetation types warrant closer inspection to determine if additional factors might be considered to make more accurate hazard ratings. Note that a significant portion of single level model errors (-1 and 1) may be between VERY LOW (0) and LOW (1) hazard levels which have been combined in Table 9.

Table 10. Mismatch between R1-SDB FIA plots ("reality") and R1-Veg category rating assigned to R1-VMap ("modelled") using the ALLPINE model.

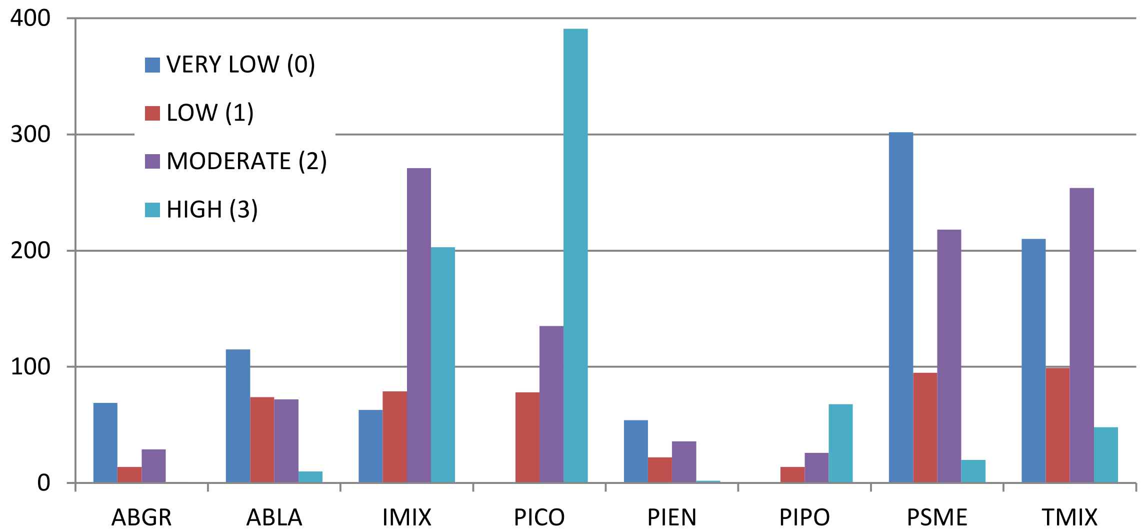
	modelled as higher hazard than reality*			reality higher hazard than modelled**			Number of Plots
Dom60	-2	-1	0	1	2	3	
ABGR		61%	12%	26%	1%		113
ABLA		30%	39%	27%	4%	1%	271
BEPA			100%				1
CELE3			100%				1
IMIX	10%	9%	48%	33%			616
JUNIP		0%	40%	60%			5
LALY		67%	33%				3
LAOC		29%	62%	9%			34
PIAL		18%	80%	1%	1%		96
PICO	2%	19%	76%	3%	0%		604
PIEN	19%	36%	32%	12%			114
PIFL2	11%	16%	63%	11%			19
PIMO3			100%				2
PIPO	3%	24%	73%				108
POPUL			100%				1
POTR5		71%	29%				7
PSME	19%	35%	26%	18%	3%		635
THPL		8%	69%	13%	10%		39
TMIX	16%	29%	38%	16%	1%		611
TSHE		76%	12%	12%			17
TSME	7%	44%	30%	19%			27
Grand Total	10%	26%	46%	17%	1%	0%	3324

*Mismatches where the model overestimated hazard by more than one level (i.e. mismatch of -2) that occurred more than 10% of the time are highlighted in red
**Mismatches where the model underestimated hazard by any amount more than 25% of the time are highlighted in yellow

Bimodal data

One important source of mismatch error is a binomial distribution of the plot hazard ratings. For example, several Dom60 cover types had plot hazard ratings of 0 or 2 (Fig. 2), but when a hazard rating was assigned to the Dom60 group the decision tree resulted in assignment of hazard rating 1. Although this approximates an "average" of plot ratings, it results in a high rate of hazard misclassification.

Regionally, this misclassification was particularly strong in PSME and TMIX. We conducted a cursory evaluation of several additional factors at the Regional level that might help divide stands with VERY LOW (0) from MODERATE (2) hazard. These factors included elevation, aspect, slope and CD. Identification of a factor that predicted placement of plots into one or the other hazard rating would greatly decrease misclassification errors. Unfortunately, none of the most likely factors evaluated appeared to be useful. Assessment was visual (graphics) and a full statistical analyses of potential variables may be needed. However, we feel this would be most appropriate at the Forest level if warranted.



Rating		ABGR	ABLA	IMIX	PICO	PIEN	PIPO	PSME	TMIX
# of Plots	0	69	115	63		54	0	302	210
	1	14	74	79	78	22	14	95	99
	2	29	72	271	135	36	26	218	254
	3	1	10	203	391	2	68	20	48
Total#		**113**	**271**	**616**	**604**	**114**	**108**	**635**	**611**

Figure 2. All Dom60 vegetation types for the Region with >100 FIA plots in the R1-SDB. Several types show a bimodal distribution of 1/3 or more of plots in the VERY LOW (0) and MODERATE (2) hazard classes (circled in red). PSME and TMIX are of greatest impact to overall model error rates due to the high number of plots in these groups. This data is for the ALL PINE model.

Age of Data

Since our first models were completed the Region updated the R1-SDB dataset of FIA plots. This new dataset (ver. 2007) has approximately half of the plot data replaced by information gathered since 2003. Using the same Dom60/Size Class model, and the thresholds used in our original calculations (Table 7) we recalculated the ALLPINE, LPP, and PP models. The updated calculations resulted in some changes in some hazard ratings. Many of these were between VERY LOW (0) and LOW (1) which was considered of little importance, especially since these two ratings might best be combined for managers. However, there were a couple of changes that did appear important. The updated LPP model assigned PICO 5-9.9' and PICO 10-14.9" to MODERATE (2) hazard rather than HIGH (3). This same adjustment was suggested for PIFL2 5-9.9" in the ALLPINE model.

These suggested hazard rating shifts likely reflect recent changes in stand conditions due to the mountain pine beetle (MBP) outbreak. Because Canopy Cover was indicated by statistics to be a relatively unimportant factor in the hazard rating model developed using the largely pre-outbreak data, the recent drop in stand density from MPB-caused mortality is not reflected in the Dom60/Size Class model. Although average tree diameter will decrease as MPB remove the larger trees, many LPP stands are similar enough in size that most stems fit within one of the Size Class categories, especially the 5-9.9" DBH Size Class. Thus, plot-level hazard rating that uses stand density (Randall et al., 2011) may now be

lower after MPB activity, yet the hazard rating of that same plot using only Dom60 and Size Class assignment would stay the same.

Ultimately, this means that R1-VMap coverages created after significant MPB-caused mortality has occurred will likely show high hazard remaining in stands that have already sustained MPB activity. As with use of older R1-VMap coverages (pre-MPB outbreak) this stand density alteration due to MPB activity would need to be accounted for to represent current conditions. With new R1-VMap products coming on board we will have to re-create our hazard ratings which may require use of a model that include Canopy Cover or a completely different approach all together.

Updating R1-VMap

VMap is a geospatial database that allows for editing of polygon labels when better local information exists to do so. Updates and corrections to the R1-VMap product will increase accuracy of landscape pine bark beetle hazard depiction. Forest or analyses area maps that have VMap polygons edited to account for better local data sources can have the Regional (or updated) hazard matrix attached. In fact, our hazard matrix can be applied to any spatial dataset that uses R1-ExVeg classifications of Dom60 and tree size class.

INDIVIDUALIZING HAZARD RATINGS

It is important to note that a more complicated model of hazard rating for use in R1-VMap is not indicated by our evaluation of the data. Much of the error in the models is due to the R1-ExVeg classification system using categories that do not reflect environmental thresholds biologically important to MPB. Until more appropriate divisions can be obtained for modeling, a high level of misclassification of bark beetle hazard in R1-VMAP will remain.

However, a model more specific to a given area or Forest (versus Region) may be obtained by recalculating hazard ratings using only plots from the Forest. There are also some predominant Dom60 cover types that would benefit from consideration of additional factors (e.g. Canopy Cover) or that have a binomial distribution where one of the two predominant hazard ratings would be more appropriate than the middle or average rating.

Two examples of re-evaluations are given in Appendix D. The Gallatin NF example looks at Forest-specific alterations to the Regional hazard ratings. This was prompted by the 15% error in the MODERATE hazard type across the forest (Table 9). The Lolo NF example looks at the R1-VMap polygons within an analyses area to explore uncertainty in the hazard rating of the IMIX cover type.

Although not explored in any example, our evaluation of the updated FIA data suggests that for PIFL2 5-9.9” in the ALLPINE model, and PICO 5-9.9’ and PICO 10-14.9” in the LPP model the HIGH (3) hazard rating may need to be degraded to MODERATE (2) to reflect recent MPB activity that would have lowered stand density below the high-hazard threshold. One way to address this would be to consider Canopy Cover in these categories. For example, if canopy cover is <60% (or <40%) HIGH hazard is maintained, but if below that threshold the hazard is dropped to MODERATE.

If Forests want to change ratings they should work with FHP and be prepared to document reasons for all changes to maintain repeatability and supportability should results be questioned.

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ACKNOWLEDGEMENTS

We wish to thank Zack Holden for assistance in use of R statistical packages. We also thank Gregg DeNitto and Joel Egan for review and comments on earlier drafts.

APPENDICIES

APPENDIX A: Individual hazard rating error rates for each of the six variable models tested for 4 individual pine host groups and for all pine species together (ALL PINE) (results from *RandomForest* evaluation)

LODGEPOLE PINE

DomGroup 60% Plurality

	0	1	2	3	error
0	1530	13	202	0	12%
1	193	16	90	94	96%
2	304	6	228	212	70%
3	42	0	96	298	32%

DomGroup 60% Plurality/Size Class

	0	1	2	3	error
0	1624	19	102	0	7%
1	206	90	73	24	77%
2	333	28	200	189	73%
3	51	0	88	297	32%

DomGroup 60% Plurality/Canopy Cover

	0	1	2	3	error
0	1595	22	128	0	9%
1	247	39	65	42	90%
2	344	4	246	156	67%
3	43	0	122	271	38%

Size Class/Canopy Cover

	0	1	2	3	error
0	1465	52	228	0	16%
1	230	71	92	0	82%
2	446	19	285	0	62%
3	203	0	233	0	100%

DomGroup 60% Plurality/Size Class/Canopy Cover

	0	1	2	3	error
0	1605	41	99	0	8%
1	210	96	73	14	76%
2	355	30	228	137	70%
3	50	0	116	270	38%

DomGroup 60% Plurality/Size Class/CanopyCover /Continental Divide

	0	1	2	3	error
0	1572	72	78	23	10%
1	204	109	59	21	72%
2	328	42	203	177	73%
3	45	0	74	317	27%

PONDEROSA PINE

DomGroup 60% Plurality

	0	1	2	3	error
0	2907	0	0	0	0%
1	105	0	12	0	100%
2	193	0	63	0	75%
3	11	0	33	0	100%

DomGroup 60% Plurality/Size Class

	0	1	2	3	error
0	2907	0	0	0	0%
1	105	10	2	0	91%
2	193	1	62	0	77%
3	11	0	33	0	100%

DomGroup 60% Plurality/Canopy Cover

	0	1	2	3	error
0	2907	0	0	0	0%
1	105	10	2	0	91%
2	193	4	48	11	81%
3	11	0	13	20	55%

Size Class/Canopy Cover

	0	1	2	3	error
0	2907	0	0	0	0%
1	117	0	0	0	100%
2	256	0	0	0	100%
3	44	0	0	0	100%

DomGroup 60% Plurality/Size Class/Canopy Cover

	0	1	2	3	error
0	2902	3	2	0	0%
1	105	9	3	0	92%
2	193	1	49	13	81%
3	11	0	17	16	64%

DomGroup 60% Plurality/Size Class/CanopyCover /Continental Divide

	0	1	2	3	error
0	2902	3	2	0	<1%
1	104	9	4	0	92%
2	192	2	47	15	82%
3	11	0	16	17	61%

WHITEBARK/LIMBER PINE

DomGroup 60% Plurality

	0	1	2	3	error
0	2484	0	0	0	0%
1	431	6	1	6	99%
2	243	6	0	21	100%
3	51	6	0	69	45%

DomGroup 60% Plurality/Size Class

	0	1	2	3	error
0	2484	0	0	0	0%
1	431	11	0	2	98%
2	243	3	0	24	100%
3	53	0	1	72	43%

DomGroup 60% Plurality/Canopy Cover

	0	1	2	3	error
0	2484	0	0	0	0%
1	431	9	2	2	98%
2	243	4	9	14	97%
3	52	0	5	69	45%

Size Class/Canopy Cover

	0	1	2	3	error
0	2484	0	0	0	0%
1	444	0	0	0	100%
2	270	0	0	0	100%
3	126	0	0	0	100%

DomGroup 60% Plurality/Size Class/Canopy Cover

	0	1	2	3	error
0	2478	6	0	0	<1%
1	431	10	2	1	98%
2	243	2	12	13	96%
3	51	0	6	69	45%

DomGroup 60% Plurality/Size Class/CanopyCover /Continental Divide

	0	1	2	3	error
0	2344	88	46	6	6%
1	352	46	40	6	90%
2	174	15	63	18	77%
3	34	0	23	69	45%

WESTERN WHITE PINE*

DomGroup 60% Plurality

	0	1	2	error
0	1861	0	0	0%
1	230	0	1	100%
2	97	1	0	10%

DomGroup 60% Plurality/Size Class

	0	1	2	error
0	1861	0	0	0%
1	231	0	0	100%
2	98	0	0	10%

DomGroup 60% Plurality/Canopy Cover

	0	1	2	error
0	1860	1	0	<1%
1	231	0	0	100%
2	98	0	0	100%

Size Class/Canopy Cover

	0	1	2	error
0	1861	0	0	0%
1	231	0	0	100%
2	98	0	0	100%

DomGroup 60% Plurality/Size Class/Canopy Cover

	0	1	2	error
0	1844	15	2	<1%
1	223	8	0	97%
2	97	1	0	100%

Host model only applicable west of Continental Divide

To understand the confusion matrix reported by *RandomForest* output, consider that each row represents all plots within the given hazard rating class (based on plot-level variables). Along the row, individual columns show how many of those plots the new model (using Dom60 and Size Class) predicted would be in each hazard rating. For example, in the model using only DomGroup 60% Plurality to predict hazard in LODGEPOLE, of the 436 plots with a High (3) hazard rating, the 1-variable model correctly predicted 298 plots as being High hazards, placing mis-categorized plots into Moderate (2) hazard (n=96) or Very Low (0) hazard (n=42). In short, this analysis gives an idea of the similarity of the two methods of plot hazard prediction

APPENDIX B: Hazard ratings and plot counts for five host models using Dominance Group 60% Plurality / Size Class categories

BARK BEETLES, PRINCIPALLY MOUNTAIN PINE BEETLE, In ALL PINE HOST SPECIES (ALL PINE)

HAZARD RATING*					SAMPLE SIZE*				
Dominance Group 60% Plurality[1]	Size Class (inches DBH)				Dominance Group 60% Plurality[1]	Size Class (inches DBH)			
	0.0-4.9 Total	05.0-09.9 Total	10.0-14.9 Total	15.0+ Total		0.0-4.9 Total	05.0-09.9 Total	10.0-14.9 Total	15.0+ Total
ABGR	1	1	1	1	ABGR	4	10	34	65
ABLA	1	1	1	0	ABLA	35	97	100	39
BEPA	0	0	0	0	BEPA	0	0	1	0
CELE3	0	0	0	0	CELE3	0	1	0	0
IMIX	1	2	2	2	IMIX	29	195	265	127
JUNIP	0	1 (not 2)	0	0	JUNIP	0	4	1	0
LALY	0	0	1 (not 0)	1	LALY	0	0	1	2
LAOC	1	1	2	1	LAOC	5	9	10	10
PIAL	1	3	3	3	PIAL	7	30	43	16
PICO	1	3	3	3	PICO	89	372	138	5
PIEN	1	2	2	1	PIEN	6	13	44	51
PIFL2	1	3	3 (not 2)	3	PIFL2	7	10	2	0
PIMO3	0	2	3	3	PIMO3	0	1	1	0
PIPO	1	3	3	3	PIPO	11	16	41	40
POPUL	0	0	0	0	POPUL	1	0	0	0
POTR5	0	1	1	1 (not 0)	POTR5	0	3	3	1
PSME	1	1	2	1	PSME	19	116	271	229
THPL	0	0	1	0	THPL	0	3	5	31
TMIX	1	2	2	1	TMIX	25	144	257	185
TSHE	0	1	1 (not 0)	1	TSHE	0	4	2	11
TSME	0	1	2	1	TSME	1	4	9	13

*Color coding was used to indicate sample sizes; estimates based on >10 plots has no color; on 1-9 plots are gold, and on 0 plots are orange. Hazard ratings based on <10 plots were determined using expert opinion. For calls based on 1-9 plots, changes to predicted hazard based on professional opinion are indicated as the suggested hazard with predicted in () following [e.g. "1 (not 0)"].

[1]Dominance Group 60% Pluralities of HMIX, FRPE, and TABR2 had no plots available for analyses and are not expected to have sufficient MPB host to warrant a hazard above 0 so are not included in this table.

APPENDIX B (cont.)

MOUNTAIN PINE BEETLE
In LODGEPOLE PINE (LPP)

HAZARD RATING*				
Dominance Group 60% Plurality[1]	**Size Class (inches DBH)**			
	0.0-4.9 Total	05.0-09.9 Total	10.0-14.9 Total	15.0+ Total
ABGR	0	0	1	0
ABLA	1	1	0	0
BEPA	0	0	0	0
CELE3	0	0	0	0
IMIX	1	2	2	1
JUNIP	0	0	0	0
LALY	0	0	0	0
LAOC	1	1	1	1
PIAL	0	0	0	0
PICO	1	3	3	3 (not 2)
PIEN	1	1	1	0
PIFL2	0	0	0	0
PIMO3	0	1	1 (not 0)	1
PIPO	0	0	0	0
POPUL	0	0	0	0
POTR5	0	1	1	1 (not 0)
PSME	1	1	1	0
THPL	0	0	0	0
TMIX	1	1	1	0
TSHE	0	0	0	0
TSME	0	1	1	0

SAMPLE SIZE*				
Dominance Group 60% Plurality[1]	**Size Class (inches DBH)**			
	0.0-4.9 Total	05.0-09.9 Total	10.0-14.9 Total	15.0+ Total
ABGR	4	10	34	65
ABLA	35	97	100	39
BEPA	0	0	1	0
CELE3	0	1	0	0
IMIX	29	195	265	127
JUNIP	0	4	1	0
LALY	0	0	1	2
LAOC	5	9	10	10
PIAL	7	30	43	16
PICO	89	372	138	5
PIEN	6	13	44	51
PIFL2	7	10	2	0
PIMO3	0	1	1	0
PIPO	11	16	41	40
POPUL	1	0	0	0
POTR5	0	3	3	1
PSME	19	116	271	229
THPL	0	3	5	31
TMIX	25	144	257	185
TSHE	0	4	2	11
TSME	1	4	9	13

*Color coding was used to indicate sample sizes; estimates based on >10 plots has no color; on 1-9 plots are gold, and on 0 plots are orange. Hazard ratings based on <10 plots were determined using expert opinion. For calls based on 1-9 plots, changes to predicted hazard based on professional opinion are indicated as the suggested hazard with predicted in () following [e.g. "1 (not 0)"].

[1]Dominance Group 60% Pluralities of HMIX, FRPE, and TABR2 had no plots available for analyses and are not expected to have sufficient MPB host to warrant a hazard above 0 so are not included in this table

APPENDIX B (cont.)

PINE BARK BEETLES*
In PONDEROSA PINE (PP)

HAZARD RATING**				
Dominance Group 60% Plurality[1]	Size Class (inches DBH)			
	0.0-4.9 Total	05.0-09.9 Total	10.0-14.9 Total	15.0+ Total
ABGR	0 (not 1)	0	0	0
ABLA	0	0	0	0
BEPA	0	0	0	0
CELE3	0	0	0	0
IMIX	0	0	0	1
JUNIP	0	1	0	0
LALY	0	0	0	0
LAOC	0	0	0	0
PIAL	0	0	0	0
PICO	0	0	0	0
PIEN	0	0	0	0
PIFL2	0	0	0	0
PIMO3	0	0	0	0
PIPO	**1**	**2**	**2**	**2**
POPUL	0	0	0	0
POTR5	0	0	0	0
PSME	0	0	0	0
THPL	0	0	0	0
TMIX	0	0	0	0
TSHE	0	0	0	0
TSME	0	0	0	0

SAMPLE SIZE**				
Dominance Group 60% Plurality[1]	Size Class (inches DBH)			
	0.0-4.9 Total	05.0-09.9 Total	10.0-14.9 Total	15.0+ Total
ABGR	4	10	34	65
ABLA	35	97	100	39
BEPA	0	0	1	0
CELE3	0	1	0	0
IMIX	29	195	265	127
JUNIP	0	4	1	0
LALY	0	0	1	2
LAOC	5	9	10	10
PIAL	7	30	43	16
PICO	89	372	138	5
PIEN	6	13	44	51
PIFL2	7	10	2	0
PIMO3	0	1	1	0
PIPO	11	16	41	40
POPUL	1	0	0	0
POTR5	0	3	3	1
PSME	19	116	271	229
THPL	0	3	5	31
TMIX	25	144	257	185
TSHE	0	4	2	11
TSME	1	4	9	13

*Includes activity by mountain pine beetle, western pine beetle (only present west of Continental Divide) and *Ips* beetles
**Color coding was used to indicate sample sizes; estimates based on >10 plots has no color; on 1-9 plots are gold, and on 0 plots are orange. Hazard ratings based on <10 plots were determined using expert opinion. For calls based on 1-9 plots, changes to predicted hazard based on professional opinion are indicated as the suggested hazard with predicted in () following [e.g. "1 (not 0)"].

[1]Dominance Group 60% Pluralities of HMIX, FRPE, and TABR2 had no plots available for analyses and are not expected to have sufficient MPB host to warrant a hazard above 0 so are not included in this table.

MOUNTAIN PINE BEETLE
In WHITE BARK and LIMBER PINES (WBkLmP)*

HAZARD RATING**				
Dominance Group 60% Plurality[1]	**Size Class (inches DBH)**			
	0.0-4.9 Total	05.0-09.9 Total	10.0-14.9 Total	15.0+ Total
ABGR	0	0	0	0
ABLA	1	1	1	0
BEPA	0	0	0	0
CELE3	0	0	0	0
IMIX	1	1	0	0
JUNIP	0	1	0	0
LALY	0	0	1 (not 0)	1
LAOC	0	0	0	0
PIAL	1	3	3	3
PICO	0	1	1	1 (not 0)
PIEN	0	0	1	0
PIFL2	1	2	3 (not 2)	3
PIMO3	0	0	0	0
PIPO	0	0	0	0
POPUL	0	0	0	0
POTR5	0	0	0	0
PSME	0	0	0	0
THPL	0	0	0	0
TMIX	0	1	1	0
TSHE	0	0	0	0
TSME	0	1	1 (not 0)	0

SAMPLE SIZE**				
Dominance Group 60% Plurality[1]	**Size Class (inches DBH)**			
	0.0-4.9 Total	05.0-09.9 Total	10.0-14.9 Total	15.0+ Total
ABGR	4	10	34	65
ABLA	35	97	100	39
BEPA	0	0	1	0
CELE3	0	1	0	0
IMIX	29	195	265	127
JUNIP	0	4	1	0
LALY	0	0	1	2
LAOC	5	9	10	10
PIAL	7	30	43	16
PICO	89	372	138	5
PIEN	6	13	44	51
PIFL2	7	10	2	0
PIMO3	0	1	1	0
PIPO	11	16	41	40
POPUL	1	0	0	0
POTR5	0	3	3	1
PSME	19	116	271	229
THPL	0	3	5	31
TMIX	25	144	257	185
TSHE	0	4	2	11
TSME	1	4	9	13

*See Appendix C for details on possible model alterations for east and west of the Continental Divide

**Color coding was used to indicate sample sizes; estimates based on >10 plots has no color; on 1-9 plots are gold, and on 0 plots are orange. Hazard ratings based on <10 plots were determined using expert opinion. For calls based on 1-9 plots, changes to predicted hazard based on professional opinion are indicated as the suggested hazard with predicted in () following [e.g. "1 (not 0)"].

[1]Dominance Group 60% Pluralities of HMIX, FRPE, and TABR2 had no plots available for analyses and are not expected to have sufficient MPB host to warrant a hazard above 0 so are not included in this table.

MOUNTAIN PINE BEETLE
In WESTERN WHITE PINE**

HAZARD RATING**				
Dominance Group 60% Plurality[1]	Size Class (inches DBH)			
	0.0-4.9 Total	05.0-09.9 Total	10.0-14.9 Total	15.0+ Total
ABGR	0 (not 1)	0	1	0
ABLA	0	0	0	0
BEPA	0	0	0	0
CELE3	0	0	0	0
IMIX	1	0	0	0
JUNIP	0	0	0	0
LALY	0	0	0	0
LAOC	0	1	0	0
PIAL	0	0	0	0
PICO	0	0	0	0
PIEN	1	1	0	0
PIFL2	0	0	0	0
PIMO3	0	1	2	3
PIPO	0	0	0	0
POPUL	0	0	0	0
POTR5	0	0	0	0
PSME	0	0	0	0
THPL	0	0	1	0
TMIX	1	1	0	0
TSHE	0	1	1 (not 0)	1
TSME	0	1	1	0

SAMPLE SIZE**				
Dominance Group 60% Plurality[1]	Size Class (inches DBH)			
	0.0-4.9 Total	05.0-09.9 Total	10.0-14.9 Total	15.0+ Total
ABGR	4	10	34	65
ABLA	22	83	88	35
BEPA	0	0	1	0
CELE3	0	0	0	0
IMIX	19	115	193	112
JUNIP	0	0	0	0
LALY	0	0	1	2
LAOC	5	9	10	10
PIAL	1	2	13	2
PICO	22	157	75	2
PIEN	3	4	17	32
PIFL2	0	0	0	0
PIMO3	0	1	1	0
PIPO	5	2	12	36
POPUL	0	0	0	0
POTR5	0	2	1	0
PSME	15	58	174	149
THPL	0	3	5	31
TMIX	22	107	201	173
TSHE	0	4	2	11
TSME	1	4	9	13

*only applicable west of Continental Divide where white pine occurs

**Color coding was used to indicate sample sizes; estimates based on >10 plots has no color; on 1-9 plots are gold, and on 0 plots are orange. Hazard ratings based on <10 plots were determined using expert opinion. For calls based on 1-9 plots, changes to predicted hazard based on professional opinion are indicated as the suggested hazard with predicted in () following [e.g. "1 (not 0)"].

[1]Dominance Group 60% Pluralities of HMIX, FRPE, and TABR2 had no plots available for analyses and are not expected to have sufficient MPB host to warrant a hazard above 0 so are not included in this table.

APPENDIX C: Alterations to model for MPB in whitebark and limber pines based on Continental Divide

MOUNTAIN PINE BEETLE
In WHITE BARK and LIMBER PINES

HAZARD RATING*2				
Dominance Group 60% Plurality1	**Size Class (inches DBH)**			
	0.0-4.9 Total	05.0-09.9 Total	10.0-14.9 Total	15.0+ Total
ABGR	0	0	0	0
ABLA	1	1 (E=2)	1 (E=2)	0 (suggest E=2)
BEPA	0	0	0	0
CELE3	0	0	0	0
IMIX	1 (W=0)	1 (W=0; E=2)	0 (E=2)	0 (E=2)
JUNIP	0	1	0	0
LALY	0	0	1 (not 0)	1
LAOC	0	0	0	0
PIAL	1	3	3	3
PICO	0	1	1 (W=0)	1 (not 0) W=0)
PIEN	0	0 (suggest E=1)	1 (W=0)	0 (E=1)
PIFL2	1	2	3 (not 2)	3
PIMO3	0	0	0	0
PIPO	0	0	0	0
POPUL	0	0	0	0
POTR5	0	0	0	0
PSME	0	0 (E=1)	0 (E=1)	0
THPL	0	0	0	0
TMIX	0	1	1 (W=0; E=2)	0 (E=2)
TSHE	0	0	0	0
TSME	0	1	1 (not 0)	0

*Color coding was used to indicate sample sizes; estimates based on >10 plots has no color; on 1-9 plots are gold, and on 0 plots are orange. Hazard ratings based on <10 plots were determined using expert opinion. For calls based on 1-9 plots, changes to predicted hazard based on professional opinion are indicated as the suggested hazard with predicted in () following [e.g. “1 (not 0)”].

1Dominance Group 60% Pluralities of HMIX, FRPE, and had no plots available for analyses and are not expected to have sufficient MPB host to warrant a hazard above 0 so are not included in this table.

2Hazard rating changes (GREEN FONT) from Regional model (BLACK FONT) for East (E) and (W) of the Continental Divide; values in green that are “suggested” have fewer than 10 plots for decision making.

APPENDIX C (cont.)

MOUNTAIN PINE BEETLE
In WHITE BARK and LIMBER PINES

EAST SIDE SAMPLE SIZE (n=1134)*				
Dominance Group 60% Plurality[1]	**Size Class (inches DBH)**			
	0.0-4.9 Total	05.0-09.9 Total	10.0-14.9 Total	15.0+ Total
ABGR	0	0	0	0
ABLA	13	14	12	4
BEPA	0	0	0	0
CELE3	0	1	0	0
IMIX	10	80	72	15
JUNIP	0	4	1	0
LALY	0	0	0	0
LAOC	0	0	0	0
PIAL	6	28	30	14
PICO	67	215	63	3
PIEN	3	9	27	19
PIFL2	7	10	2	0
PIMO3	0	0	0	0
PIPO	6	14	29	4
POPUL	1	0	0	0
POTR5	0	1	2	1
PSME	4	58	97	80
THPL	0	0	0	0
TMIX	3	37	56	12
TSHE	0	0	0	0
TSME	0	0	0	0

WEST SIDE SAMPLE SIZE (n=2190)*				
Dominance Group 60% Plurality[1]	**Size Class (inches DBH)**			
	0.0-4.9 Total	05.0-09.9 Total	10.0-14.9 Total	15.0+ Total
ABGR	4	10	34	65
ABLA	22	83	88	35
BEPA	0	0	1	0
CELE3	0	0	0	0
IMIX	19	115	193	112
JUNIP	0	0	0	0
LALY	0	0	1	2
LAOC	5	9	10	10
PIAL	1	2	13	2
PICO	22	157	75	2
PIEN	3	4	17	32
PIFL2	0	0	0	0
PIMO3	0	1	1	0
PIPO	5	2	12	36
POPUL	0	0	0	0
POTR5	0	2	1	0
PSME	15	58	174	149
THPL	0	3	5	31
TMIX	22	107	201	173
TSHE	0	4	2	11
TSME	1	4	9	13

*Color coding was used to indicate sample sizes; estimates based on >10 plots has no color; on 1-9 plots are gold, and on 0 plots are orange. Hazard ratings based on <10 plots were determined using expert opinion. For calls based on 1-9 plots, changes to predicted hazard based on professional opinion are indicated as the suggested hazard with predicted in () following [e.g. "1 (not 0)"].

[1]Dominance Group 60% Pluralities of HMIX, FRPE, and TABR2 had no plots available for analyses and are not expected to have sufficient MPB host to warrant a hazard above 0 so are not included in this table.

APPENDIX D: Exploring forest level adjustments

The Regional level MPB hazard ratings for ALL PINE, LPP, PP, WBkLmP and WWP may be re-evaluated at the Forest Level if the REGION model has >10% error in a hazard level of interest (Table 9). The following is an example of some of the analyses and changes that were explored to create what we hope are more accurate depictions of MPB stand susceptibility. In these examples the ALL PINE model was used although any one of the host-specific models (LPP, PP, WBkP-LmP, and WWP) may be similarly evaluated and altered. This process should be done cooperatively with Forest personnel involved in landscape analyses and an FHP entomologist familiar with this modeling.

Model adjustments based on Forest-specific R1-SDB plots – the Gallatin NF example

Table A shows the results of analysis using only FIA plots found on the Gallatin NF. Of the nine possible changes suggested by the Gallatin-only data, most are in Dom60 vegetation types that have been identified as having a bimodal distribution Regionally or at least a wide range of hazard levels but only three are based on 10 or more plots.

Changes to the Regional model hazard rating should be considered carefully and justifications recorded. In this Gallatin NF case, we decided up front that three suggested changes were based on too few of plots, did not come from Dom60 types likely to have highly variable data, and were not helpful in highlighting areas most likely to have high susceptibility to MPB (i.e. changes in PIAL, PICO and PIFL2). Table B provides the justifications used for the other five changes in ALL PINE hazard rating specific to the Gallatin NF.

Making the five suggested changes results in a better overall model of hazard rating for the Forest. Table C shows the Gallatin ALL PINE model improvement over the Regional ALL PINE model (also shown in Table 9). A closer look at plot-level mismatch in hazard rating indicates that the ratings given to FIA ground plots using Randal and others (2011b) were correctly predicted by our model using R1-ExVeg characteristics about 60% of the time. However, this does not include the expected decrease in overall error if hazard levels VERY LOW (0) and LOW (1) are combined. A few instances where 1) mismatches were overestimated more than one level in the model (-2) or 2) mismatches were consistently underestimated by the model >25% of the time are highlighted. Further exploration of these mismatch errors may be warranted depending on the modelling goals or the composition of the analyses area within the Gallatin NF.

TABLE A: GALLATIN NF HAZARD RATING for ALL PINE HOST SPECIES

HAZARD RATING*				
Dominance Group 60% Plurality[1]	Size Class (inches DBH)			
	0.0-4.9 Total	05.0-09.9 Total	10.0-14.9 Total	15.0+ Total
ABGR	1	1	1	1
ABLA	1	1	1	1 (not 3) 0
BEPA	0	0	0	0
CELE3	0	0	0	0
IMIX	1	3 2	3 2	3 2
JUNIP	0	1	0	0
LALY	0	0	1	1
LAOC	1	1	2	1
PIAL	1	2 3	3	3
PICO	1	3	3	2 3
PIEN	1	2	2	1
PIFL2	1	2 3	3	3
PIMO3	0	2	3	3
PIPO	1	3	3	3
POPUL	0	0	0	0
POTR5	0	1	1	1
PSME	1	1	0 2	1
THPL	0	0	1	0
TMIX	1	2	2	2 1
TSHE	0	1	1	1
TSME	0	1	2	1

SAMPLE SIZE*				
Dominance Group 60% Plurality[1]	Size Class (inches DBH)			
	0.0-4.9 Total	05.0-09.9 Total	10.0-14.9 Total	15.0+ Total
ABGR				
ABLA	3	4	3	1
BEPA				
CELE3				
IMIX	1	12	16	5
JUNIP	0	1	1	0
LALY				
LAOC				
PIAL	1	4	10	6
PICO	8	20	13	2
PIEN	0	2	8	6
PIFL2	0	1	0	0
PIMO3				
PIPO				
POPUL				
POTR5				
PSME	0	9	15	22
THPL				
TMIX	0	11	23	4
TSHE				
TSME				

*Purple numbers indicate Regional ALL PINE hazard ratings. Larger red numbers indicated changes suggested by Gallatin NF-only plot analyses that were accepted and changed; blue numbers indicate changes suggested but not changed. Color coding of cells was used to indicate sample sizes; estimates based on >10 plots has no color; on 1-9 plots are gold, and on 0 plots are orange. If the Dom60 group did not appear in the Gallatin FIA plot dataset it is colored gray. Hazard ratings based on <10 plots were determined using expert opinion. For calls based on 1-9 plots, changes to predicted hazard based on professional opinion are indicated as the suggested hazard with predicted in () following [e.g. "1 (not 0)"].

[1]Dominance Group 60% Pluralities of HMIX, FRPE, and TABR2 had no plots available for analyses and are not expected to have sufficient MPB host to warrant a hazard above 0 so are not included in this table.

TABLE B: justification for the five changes recommended for the Gallatin NF, ALL PINE hazard rating in R1-VMAP

Dom60 vegetation type	Size Class	Change made	Reasoning for recommended change
ABLA	15+	change from 0 to 1	a move from 0 to 3 is too large based on one plot; ABLA on the Gallatin NF is not typically considered high hazard to MPB; changing to a 1 to be more in line with the rest of ABLA type is reasonable although 0 and 1 hazard levels may be combined so may be unnecessary
IMIX	05.0-09.9	change from 2 to 3	IMIX is a vegetation type that by definition is going to have wide variability in composition over the Region; IMIX on Gallatin appears to have more pine host than IMIX averaged over the Region
	10.0-14.9	change from 2 to 3	IMIX is a vegetation type that by definition is going to have wide variability in composition over the Region; IMIX on Gallatin appears to have more pine host than IMIX averaged over the Region
	15.0+	change from 2 to 3	IMIX is a vegetation type that by definition is going to have wide variability in composition over the Region; IMIX on Gallatin appears to have more pine host than IMIX averaged over the Region
PSME	10.0-14.9	change from 2 to 0	PSME is strongly bimodal vegetation type; for the Gallatin a 0 hazard is more appropriate than a 2 hazard
TMIX	15.0+	change from 1 to 2	TMIX is a strongly bimodal vegetation type that, over the Region, had an average hazard rating of 1; for the Gallatin a 2 hazard rating is more appropriate

TABLE C: Comparison of %area predicted to be in each of three hazard rating classes based on plot-level hazard estimates and R1-ExVeg classification hazard estimates using the ALL PINE hazard model and FIA periodic plot data (1993-2002) for the Northern Region (REGIONAL) or Gallatin National Forest (FOREST).

		BASED ON PLOT STAND HAZARD RATINGS			BASED ON DOM60/SIZE CLASS HAZARD RATING			DIFFERENCES BETWEEN TWO RATINGS**		
Forest Name (Number)	#of Plots	0&1* (very low + low)	2 (moderate)	3 (high)	0&1* (very low + low)	2 (moderate)	3 (high)	0&1* (very low + low)	2 (moderate)	3 (high)
REGIONAL ALL PINE MODEL	212	36%	28%	36%	30%	43%	26%	6%	**-15%**	9%
FOREST ALL PINE MODEL	212	36%	28%	36%	35%	23%	42%	0%	6%	-6%

TABLE D: A closer evaluation of the mismatch between the hazard ratings given to FIA plots located on the Gallatin NF ("reality") and the hazard given to the R1-VMAP category of that plot ("modelled").

	modelled as higher hazard than reality			reality higher hazard than modelled			
Dom60	-2	-1	0	1	2	Number of Plots	Comments or Concerns
ABLA		27%	45%	9%	18%	11	sample size only 11; overall distribution suggests model is appropriate; may be worth exploring further if ABLA is a dominant type in a smaller analyses area
IMIX	9%	26%	65%			34	
JUNIP			100%			2	
PIAL		14%	86%			21	
PICO	5%	14%	79%	2%		43	
PIEN	13%	31%	38%	19%		16	PIEN may be rated higher than wanted and may need further evaluation depending on modelling goals
PIFL2		100%	0%			1	(sample size = 1)
PSME		39%	37%	22%	2%	46	PSME still contains a wide range of hazard levels and may need further evaluation depending on modelling goals
TMIX	11%	5%	63%	21%		38	Review of plot data shows TMIX 10-14.9" is where many high hazard plots were mis-identified; this may warrant further evaluation depending on modelling goals
Grand Total	5%	22%	60%	11%	1%	212	

Model adjustments based on R1-VMap polygons – the Lolo NF project area example

Reassessing hazard ratings for areas smaller than a National Forest should not be done by reanalyzing FIA plots for that area; there will likely be too few to base changes on. In some cases both the Regional models and the Forest-level models will have vegetation types (Dom60) that contain more error than is acceptable for the smaller analyses area. One possible way to further refine hazard for these Dom60 types of concern is to examine the R1-VMap data for that analyses area. More specifically, each polygon contains information not only on the Dom60 vegetation class but the more detailed DG6040 which can be explored.

An analysis similar to what was done on the Gallatin was completed for the Lolo National Forest for the ALL PINE, LPP, and PP hazard models. Most potential changes in hazard rating at the Forest level appeared inconsequential (e.g. between ratings of VERY LOW [0] and LOW [1]), had few plots for basis (<10), and did not reflect changes potentially justified by bark beetle stand preferences. The few potential alterations we thought might be worth exploring included:

ALL PINE MODEL

- PSME 15"+ — possible increase to hazard of 2 (from 1)
- TMIX 10-14.9" and 15"+ — issues of bimodal data (ratings of 1 versus 2)
- IMIX sizes >4.9" — no hazard rating changes indicated but most plots on the Lolo with hazards of 3 that were rated lower by the model were in this group

PP MODEL

- PIPO 10-15" — possible change to hazard of 3 (from 2) but only 3 plots
- IMIX sizes >9.9" — no hazard rating changes indicated but strong bimodal distribution of data between hazard ratings 0 and 2

LPP MODEL

- No changes indicated but noticed high bimodal tendency remained in IMIX 10-14.9"

Before making changes to the hazard ratings applied to R1-VMap we wanted to know if any of these Dom60 vegetation types were common or important to the analysis area. We discovered that IMIX was both common and very likely to have pines as part of the species composition (versus other shade intolerant tree species that are not typical MPB hosts).

Within the analysis area our GIS coverage indicated 18,373 acres of IMIX type (Dom6). Because IMIX is a heterogeneous category where no single species makes up 60% or more of the basal area, greater detail on presence of pine can be gotten from DG6040 classifications. Table E shows this additional breakdown within the IMIX (Dom60) type:

Table E. Distribution of IMIX Dom60 vegetation type among Dom6040 vegetation types

Dom6040 type	Description	GIS Acres	%of Project Area
IMIX	No one tree species has 40% dominance or greater	330	1.8%
LAOC-IMIX	LAOC has 40-59% dominance; the remainder is mixed, shade intolerant species, none of which constitute 40% or more of the basal area	2,954	16.1%
PICO-IMIX	PICO has 40-59% dominance (remainder as above)	2,884	**15.7%**
PIPO-IMIX	PIPO has 40-59% dominance (remainder as above)	2,637	**14.4%**
PSME-IMIX	PSME has 40-59% dominance (remainder as above)	9,568	52.1%
	Grand Total (Dom60 IMIX type)	**18,373**	

If within the IMIX type, only the DG6040 types of PICO-IMIX and PIPO-IMIX types have the potential for MPB activity, we determined that approximately 30% of the IMIX type within the project area could have a HIGH hazard rating (15.7%+14.4%). We then broke down the PICO-IMIX and PIPO-IMIX types further by their canopy cover and assumed that canopy covers less than 40% would constitute stands of densities too low to be highly susceptible to MPB (Table F). This summary suggests that only 14% of the IMIX (Dom60) type has 40-59% pine (PICO or PIPO basal area), and over 40% canopy cover. If we assumed only the larger diameters (>9.9") and greatest density stands (>60% canopy) fully meet high hazard thresholds, the area of concern for MPB activity drops to around 3.4% of IMIX in the project area.

Table F. The breakdown of Dom60 vegetation type IMIX into subcategories most likely to have high susceptibility to mountain pine beetle. This includes the two pine-dominated DG6040 vegetation types PICO-IMIX and PIPO-IMIX, the denser stands with CANOPY COVER of 40% or greater, and the SIZE CLASS of 5"DBH or greater. Red type denotes what is likely the highest hazard areas. However, CANOPY COVER and SIZE CLASS are descriptive of the overall stand and not of the pine host type separately.

Dom60	DG6040	CANOPY COVER	TREE SIZE	ACRES in PROJECT	% of DG6040 types PICO-IMIX + PIPO IMIX	% of DG6040 types PICO-IMIX + PIPO IMIX	% of Dom60 type IMIX	% of Dom60 type IMIX
IMIX	PICO-IMIX	40 to 60%	5.0-9.9"	492	19.1%	71.5%	2.7%	10.0%
			10-14.9"	405	15.7%		2.2%	
			15"+	93	3.6%		0.5%	
		>60%	5.0-9.9"	254	9.9%		1.4%	
			10-14.9"	484	18.8%		**2.6%**	
			15"+	112	4.4%		**0.6%**	
	PIPO-IMIX	40 to 60%	5.0-9.9"	252	9.8%	28.5%	1.4%	4.0%
			10-14.9"	214	8.3%		1.2%	
			15"+	190	7.4%		1.0%	
		>60%	5.0-9.9"	42	1.6%		0.2%	
			10-14.9"	31	1.2%		**0.2%**	
			15"+	4	0.1%		**0.0%**	
			Grand Total	2573	100%		14%	

Evaluation of R1-VMap composition in the project area suggests that the Dom60 IMIX vegetation type doesn't contain many stands considered HIGH (3) hazard to MPB activity. However, if those analyzing the project area want to be liberal about identifying stands susceptible to MPB, they may choose to highlight any R1-Veg types that have a significant possibility of having HIGH (3) hazard. To make this change to R1-VMap they would adjust MODERATE (2) hazard rating to HIGH (3) in the attribute table for the IMIX (Dom6) type for all but the 0-4.9" size class. Table G is an example of the justification for these changes; information that should be reported with any changes from the Regional model.

Table G. Various traits of the IMIX (Dom60) vegetation type for the Northern Region, for the Lolo National Forest, and for a given project area. This information can be used to determine if specific changes should be made to ALL PINE hazard ratings within the project areas.

Tree Size Class	GIS Acres	R1-Hazard Rating	Lolo-specific Hazard Rating	#FIA plots on Lolo	#FIA plots on Lolo w HIGH hazard	% of FIA plots that were HIGH hazard	Possible Hazard Rating Changes for Project Area	Hazard Rating Change Discussion
0.0-4.9	1474	1	1	3	0	0	(n/a)	
05.0-09.9	6058	2	2	19	4	21%	2 or 3	Around ¼ of the FIA plots on the Lolo NF that fall into these three IMIX-size classes were given HIGH hazard (3) ratings. Thus a liberal effort to identify areas in VMAP with any likelihood of high hazard could change ratings from MODERATE (2) to HIGH (3). We also noted that these 3 categories have ~26% of the treed acres in the project area so they are important. However, when we look at all IMIX within the Project area in each size class, and choose only those stands with pine (PIPO or PICO) constituting at least 40% of plot, and canopy cover >=40%, we find only 6%, 6%, and 2% of all IMIX acres likely warrant a HIGH rating, respectively (by size class).
10.0-14.9	6846	2	2	31	8	26%	2 or 3	
15.0+	3997	2	2	21	6	29%	2 or 3	